The Full-sky Astrometric Mapping Explorer – Astrometry for the New Millennium

Scott D. Horner[1], Marvin E. Germain[2], Thomas P. Greene[3], Fred H. Harris[2], Mark S. Johnson[4], Kenneth J. Johnston[1], David G. Monet[2], Marc A. Murison[1], James D. Phillips[5], Robert D. Reasenberg[5], P. Kenneth Seidelmann[1], Sean E. Urban[1], and Richard H. Vassar[6]

Abstract.

FAME is designed to perform an all–sky, astrometric survey with unprecedented accuracy. It will create a rigid astrometric catalog of 4 $\times 10^7$ stars with $5 < m_V < 15$. For bright stars, $5 < m_V < 9$, FAME will determine positions and parallaxes accurate to < 50 μas, with proper motion errors < 50 $\mu as/year$. For fainter stars, $9 < m_V < 15$, FAME will determine positions and parallaxes accurate to < 500 μas, with proper motion errors < 500 $\mu as/year$. It will also collect photometric data on these 4 $\times 10^7$ stars in four Sloan DSS colors.

1. Introduction

NASA selected the Full-sky Astrometric Mapping Explorer (FAME) to be one of five MIDEX missions funded for a concept study. The Phase A Concept Study Report was submitted to NASA on 18 June 1999. In September 1999, NASA will select two of these five missions for flight as MIDEX-3 (CY2003 launch) and MIDEX-4 (CY2004 launch) in its Explorer program.

While not an interferometer, FAME is relevant to interferometry because of the way it complements interferometric projects, in particular the Space Interferometry Mission (SIM, cf. Shao 1999). The proper motion data from FAME, combined with *Hipparcos* (cf. Kovalevsky 1998) and other data will be ideal for use to select SIM's astrometric reference grid stars. FAME will also identify stars with nonlinear proper motions as planetary system candidates for further study by SIM, Terrestrial Planet Finder, and future ground based interferometers. The fundamental astrometric data provided at relatively low cost by FAME will help optimize the scientific return from these future projects. This is in addition to the considerable, direct, scientific return from FAME. FAME will redefine the extragalactic distance scale and provide a large, rich database of information

[1]U.S. Naval Observatory, 3450 Massachusetts Ave. NW, Washington, DC 20392-5420
[2]U.S. Naval Observatory, PO Box 1149, Flagstaff, AZ 86002-1149
[3]NASA Ames Research Center, M.S. 245-6, Moffett Field, CA 94035-1000
[4]Naval Research Laboratory, Code 8100, 4555 Overlook Ave. SW, Washington, DC 20375-5000
[5]Smithsonian Astrophysical Observatory, 60 Garden St., Cambridge, MA 02138
[6]Lockheed Martin Missiles and Space Advanced Technology Center, O/L923 B/251, 3251 Hanover St., Palo Alto, CA 94304-1191

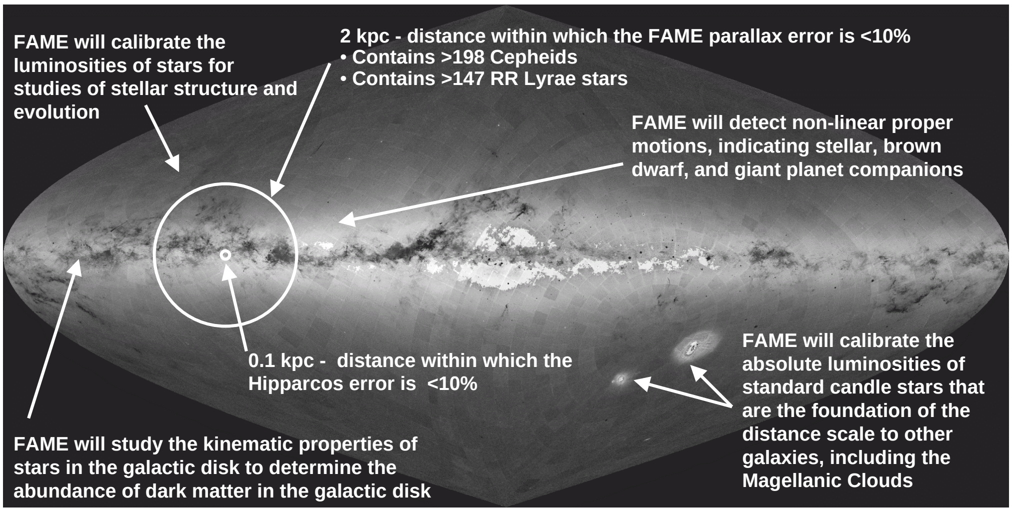

Figure 1. The principal science goals of FAME. It will not only improve on the accuracies of star positions determined by Hipparcos but also expand the volume of space for which accurate positions are known by a factor of 8000.

on stellar properties that will enable numerous science investigations in stellar structure and evolution, the dynamics of the Milky Way, and stellar companions including brown dwarfs and giant planets.

2. Science Goals

FAME will measure the positions, parallaxes, and proper motions of 4×10^7 stars with $5 < m_V < 15$. The positional accuracy will be the finest yet achieved. For $m_V = 9$ stars, the positional and parallax accuracies will be better than 50 μas, and the proper motion accuracies will be better than 50 $\mu as/year$. At $m_V = 15$, these accuracies will be degraded by only an order of magnitude. FAME will also obtain photometric data with millimagnitude accuracies on these 4×10^7 stars, observing them in four of the five Sloan Digital Sky Survey bands (g′, r′, i′, z′).

Not only will the FAME data provide a rigid, accurate, optical, astrometric grid, but it will also produce an extensive database of stellar properties that will enable research in areas across the NASA themes. Figure 1 summarizes the principal scientific objectives of FAME.

2.1. Extragalactic distance scale

FAME will calibrate the absolute luminosities of "standard candle" stars such as Cepheids and RR Lyrae stars. Figure 2 shows the coverage of the Hipparcos, SIM, and FAME missions within which distances are or will be accurate to better than 10% error. Also plotted in this figure are the known Cepheids and RR Lyrae stars. FAME has been optimized to obtain accurate distances to a

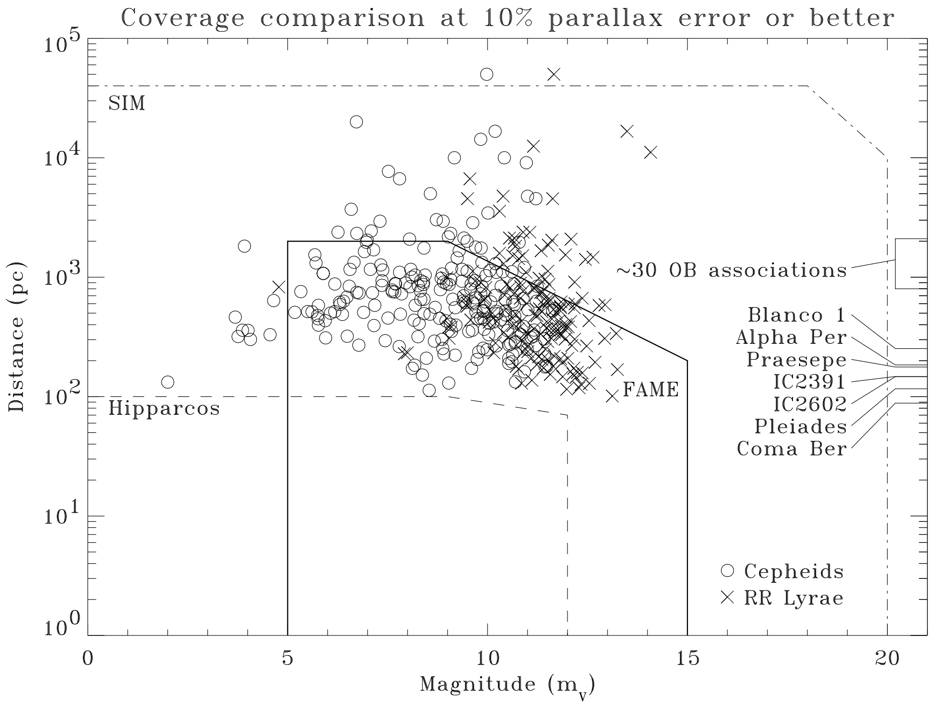

Figure 2. Comparison of the astrometric capabilities of FAME to SIM and Hipparcos. The lines indicate where achieved accuracy will be 10% parallax error or better. Known Cepheids are indicated by circles and RR Lyraes with '×'s. Distances to clusters and OB associations are indicated at the right of the figure.

large sample of Cepheids to determine the zero–point of the period–luminosity relation, calibrating the extragalactic distance scale.

2.2. Stellar Companions & Exoplanets

FAME will detect low–mass companions by measuring nonlinear proper motions of catalog stars. This will provide a definitive determination of the frequency of solar–type stars orbited by brown dwarf companions in the mass range of 10 to 80 M_{jup} with orbital periods as long as about twice the duration of the FAME mission. This will include an exploration of the transition region between giant planets and brown dwarfs, which appears to be in the range 10 to 30 M_{jup}.

2.3. Absolute Luminosities

By determining their parallaxes, FAME will calibrate the absolute luminosities of solar–neighborhood stars, including Population I and Population II stars, thus enabling diverse studies of stellar evolution and stellar structure. In the case of Population II subdwarfs, this will allow the determination of the distances and ages of galactic and extragalactic globular clusters with unprecedented accuracy.

The FAME database will also include four–color photometry for stars in the solar neighborhood. This unparalleled wealth of knowledge of fundamental stellar properties will revolutionize our understanding of stars in our quadrant of the Milky Way.

2.4. Dynamics

By providing the proper motions and parallaxes of 4 $\times 10^7$ stars, FAME will enable studies of the kinematic properties of solar neighborhood stars. In particular, we can assess the abundance and distribution of dark matter in the galactic disk with much greater sensitivity and completeness than previously possible.

We can also measure the proper motions and distances for individual stars in star forming regions for determination of the ages and kinematics of those regions.

3. Mission Design

FAME evolved from the highly successful *Hipparcos* design. As with *Hipparcos,* FAME uses two widely separated fields of view that are combined on a single focal plane to control the growth of random errors in the relative separations of stars over large angles. Unlike *Hipparcos,* however, FAME will have a large array of CCDs that will not only improve the signal to noise of the observations but will also enable the observation of many stars simultaneously.

FAME will use the solar radiation pressure on the Sun shield/solar array panels to smoothly precess its spin axis about the Sun, maintaining a separation of about 45° between the spin axis and the Sun direction. This will allow the reduction or elimination of thruster firings for precession, which results in a reduction of systematic errors introduced by breaks in the smooth motion of the spacecraft. Figure 3 illustrates the FAME observing concept.

FAME will be launched by a Delta II 7425 to a geosynchronous transfer orbit, then boosted into a geosynchronous orbit by an apogee kick motor. This orbit allows for 24-hour communication with the spacecraft, reduces the thermal impact of the Earth on the instrument, and reduces occultations and eclipses.

4. Instrument

The FAME instrument is designed, assembled, aligned, and tested by Lockheed Martin Missiles and Space Advanced Technology Center at its Palo Alto facility. The instrument has a compound mirror, consisting of two 0.6 m $\times$ 0.25 m flats mounted at a fixed “basic angle” of 81.5°. The compound mirror reflects the light from the two fields of view into a common optical train, consisting of three powered surfaces and a set of five flats to fold the 15 m focal length of the optical system into the available volume. The resulting flat focal plane combines the images from the two fields of view onto an array of twenty–four 2048 $\times$ 4096 backside illuminated CCDs.

The CCDs are clocked out in time delayed integration mode to match the rotation rate of the spacecraft. The instrument autonomously compensates for

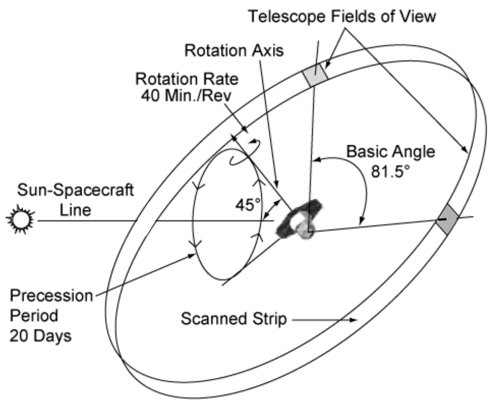

Figure 3. The rotation axis of the FAME spacecraft is pointed 45° from the Sun and precesses around the Sun with a 20 day period. The FAME spacecraft rotates with a 40 minute period. The two fields of view are normal to the rotation axis and are separated by a 81.5° basic angle.

variations in the spacecraft spin rate by analyzing bright star data on–board to calculate the spin rate and then adjusting the TDI rate accordingly.

5. Spacecraft Bus

The spacecraft bus is designed, assembled, integrated with the instrument, and tested by the Naval Research Laboratory (NRL). The bus will place the instrument in the proper orbit, provide a long-term stable platform for the instrument, and collect, buffer, and transmit the science data to the ground station.

To provide a stable platform for the instrument, all actively moving components were eliminated. The spacecraft bus thermal design and operation modes are such that constant power and temperatures are maintained to eliminate structural expansion or contraction. Passive damping is employed to maintain a low level of jitter.

Many of the subsystems used in FAME have flight heritage from *Clementine.* The NRL Naval Center for Space Technology has built and launched over 87 satellites since 1960, thus NRL's FAME team has extensive experience with rapid spacecraft development.

Figure 4 shows the FAME spacecraft in its operational configuration. The solar shield/solar array panels deploy and provide power to the spacecraft, optically and thermally shield the instrument from the Sun, and act as a solar sail to smoothly precess the spacecraft. Motorized trim tabs mounted on the edge of the solar shield can adjust the rate of precession for optimal performance.

6. Summary

In addition to its primary science objectives, FAME is an extremely valuable complement to the SIM mission. FAME, an all–sky survey, naturally comple-

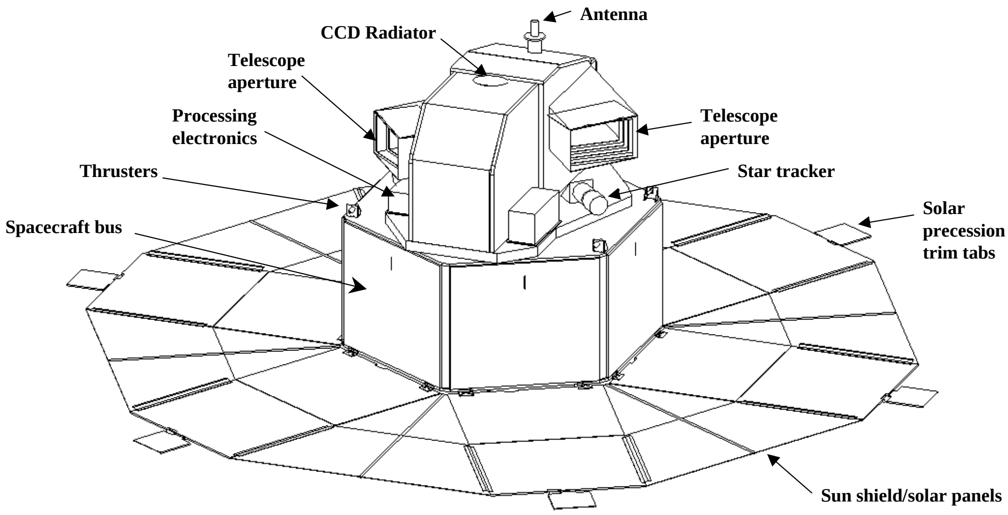

Figure 4. The FAME spacecraft after solar shield deployment

ments SIM, a pointed mission. SIM will obtain very high precision observations of a limited number of objects ($< 10,000$), whereas FAME will obtain high precision observations of a large number of objects, providing the statistical samples required for many studies (cf. Spergel 1999).

FAME provides a database of faint, astrometrically stable stars for use in selecting the SIM grid stars. This would be extremely valuable in reducing the amount of time SIM will spend observing the grid stars. It will also identify targets with nonlinear proper motions for observation with SIM to search for low–mass companions and exoplanets. SIM observing time will be expensive, both in terms of the overall cost of the SIM mission and the limited time available for the large number of key projects. The FAME database will reduce the amount of time required to observe grid stars, and identify interesting targets for exoplanet searches.

Acknowledgments. Funding for the FAME proposal development and MIDEX Phase A Concept Study were provided by the U.S. Naval Observatory, NASA Explorers Program, and Lockheed Martin Missiles and Space.

FAME is a joint development effort of the U.S. Naval Observatory, Lockheed Martin Missiles and Space Advanced Technology Center, Naval Research Laboratory, and Smithsonian Astrophysical Observatory.

References

Kovalevsky, J. 1998, ARA&A, 36, 99

Shao, M. 1999, in ASP Conf. Ser., Working on the Fringe, eds. S.C. Unwin & R.V. Stachnik (San Francisco: ASP), *these proceedings*

Spergel, D. 1999, in ASP Conf. Ser., Working on the Fringe, eds. S.C. Unwin & R.V. Stachnik (San Francisco: ASP), *these proceedings*